# How does convective self-aggregation impact precipitation extremes?


Caroline Muller

*CNRS / Laboratoire de Météorologie Dynamique (LMD)*

*Ecole Normale Supérieure Paris*

Nicolas Da Silva

*University of East Anglia UK*

Sara Shamekh

*Laboratoire de Météorologie Dynamique*

Yukari Takayabu

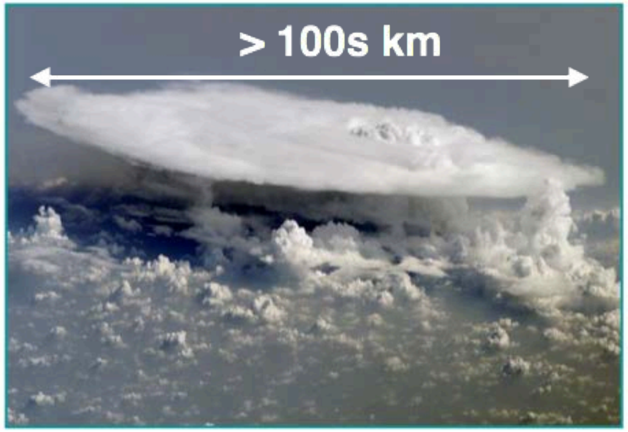
*The university of Tokyo*

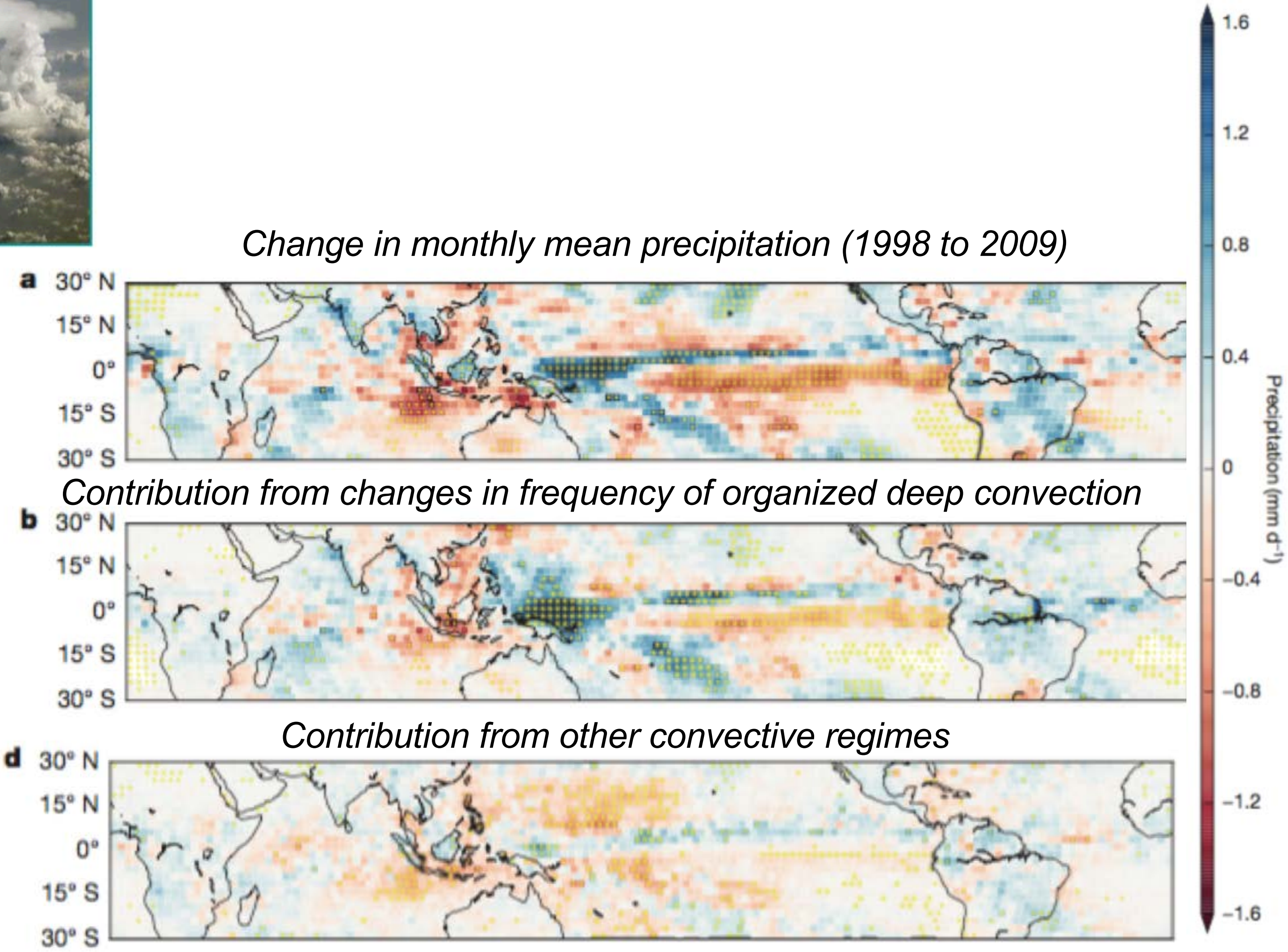


*With funding from*

# Recent trends in tropical precipitation linked to organization

*Mesoscale Convective System*



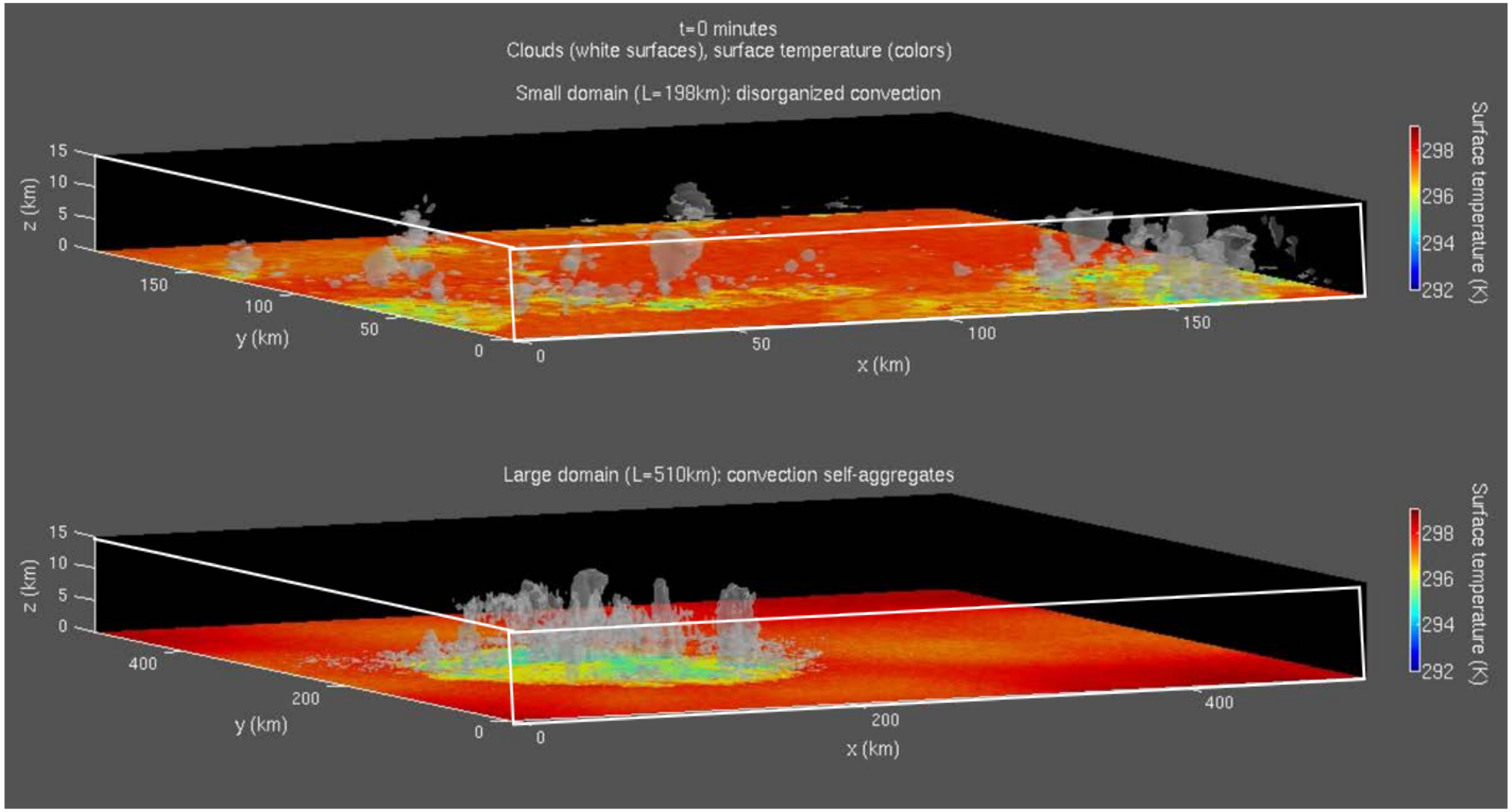




[Tan et al, Nature 2015]

# Self-aggregation of deep convection

- SAM [Khairoutdinov & Randall 03]
- SST=300K uniform
- No Coriolis (f=0)
- Doubly periodic
- No large-scale forcing
- In RCE

*Clouds over near-surface temperature in cloud-resolving model SAM*




*« pop corn » convection*

Larger domain

*Self-aggregates*

Self Aggregation = Instability of disorganized Radiative-Convective Equilibrium “pop corn” state

*[Bretherton, Blossey, Khairoutdinov, 2005; Sobel, Bellon, Bacmeister 2007; Muller, Held 2012; Emanuel, Wing, Vincent 2013; Wing Emanuel 2013; Jeevanjee Romps 2013; Khairoutdinov Emanuel, 2013; Shi Bretherton 2014; Tobin, Bony, Roca, 2012; Tobin et al, 2013; Muller Bony 2015; Arnolad Randall 2015; Coppin Bony 2015; Mapes 2016; Holloway Woolnough 2016; Tompkins Semie 2017; Wing Holloway Emanuel Muller 2017; Becker Bretherton Hohenegger Stevens 2018; Yang 2018; Muller Romps 2018 …]*

# Question addressed

How does convective self-aggregation impact precipitation extremes?

Why?

# Question addressed

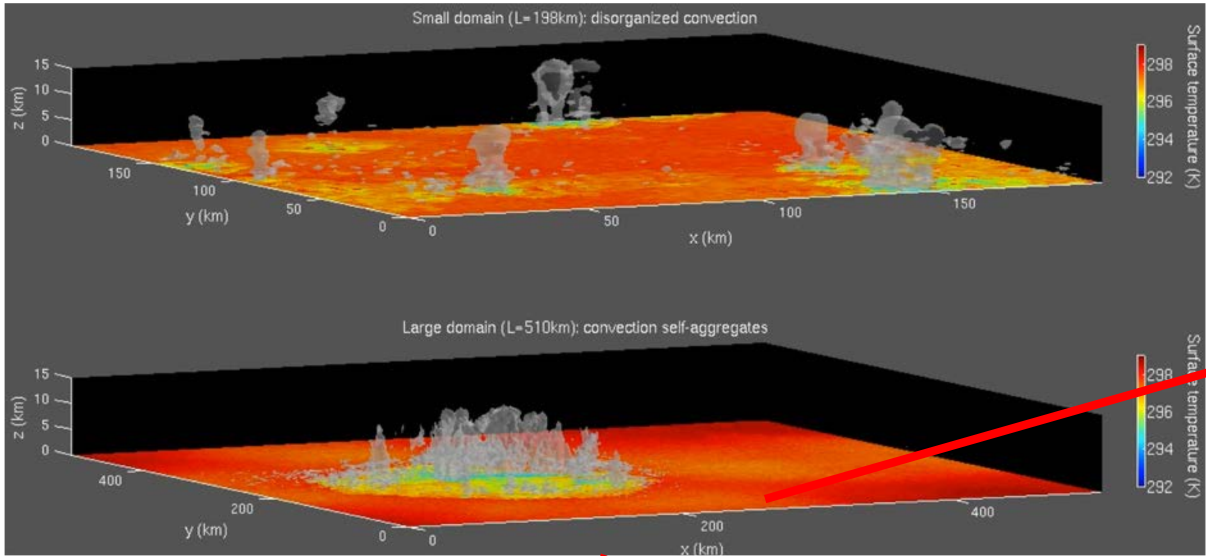
How does convective self-aggregation impact precipitation extremes?

Why?

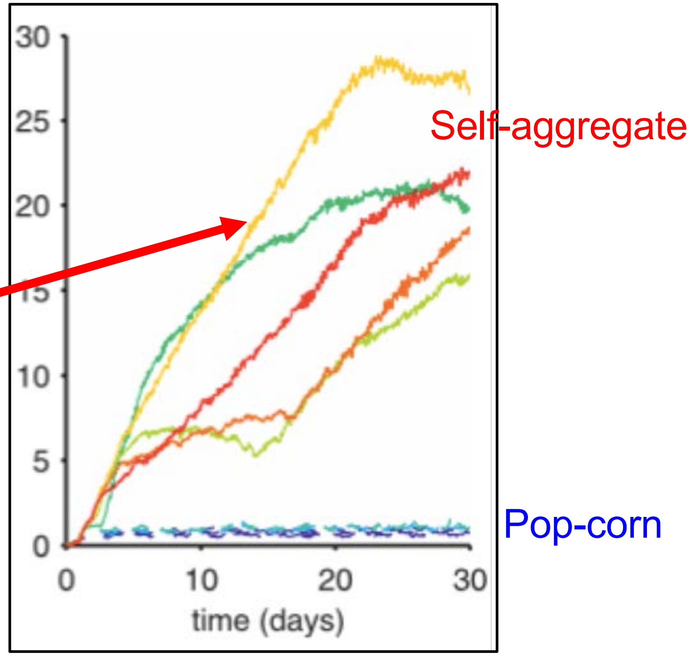
How does convective self-aggregation change with warming?

→ Sara Shamekh poster A27 session 1

# Self-aggregation

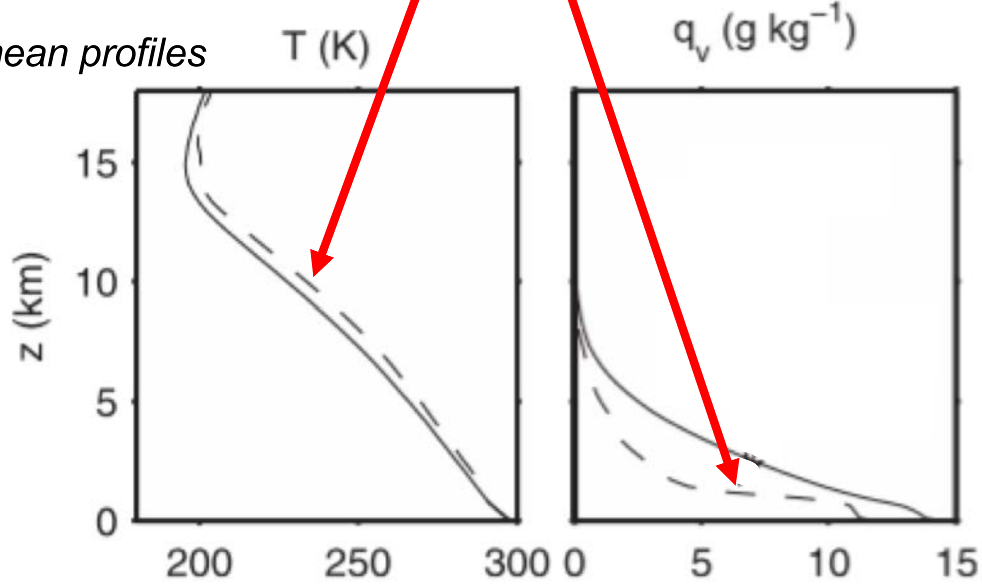



*Variance of precipitable water (mm) in simulations*




Self-aggregation leads to enhanced moisture variability (moister moist region, drier dry region)

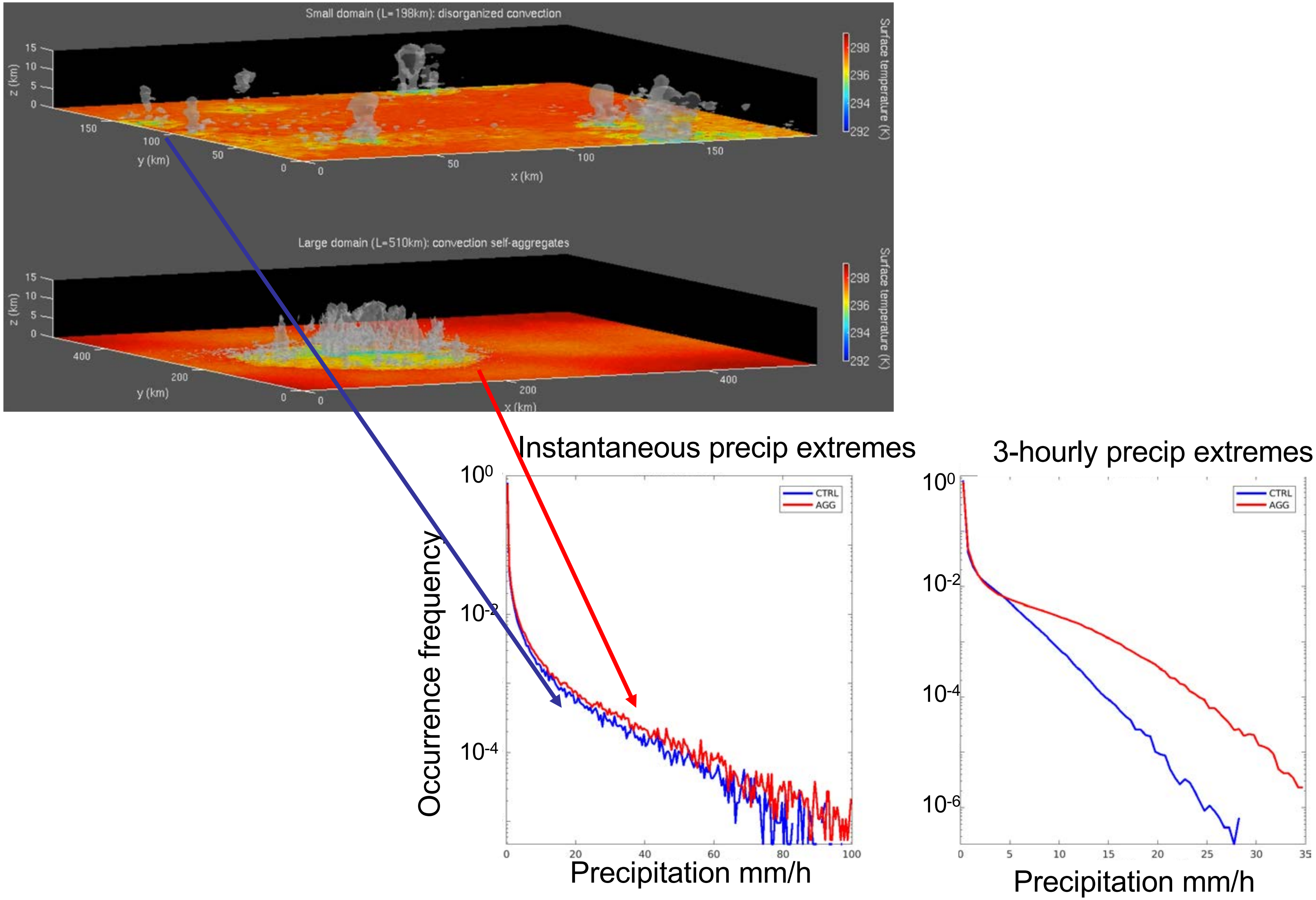
*Domain mean profiles*




- Overall drying
- Overall warming (warmer moist adiabat)

*[Muller & Held, JAS 2012]*

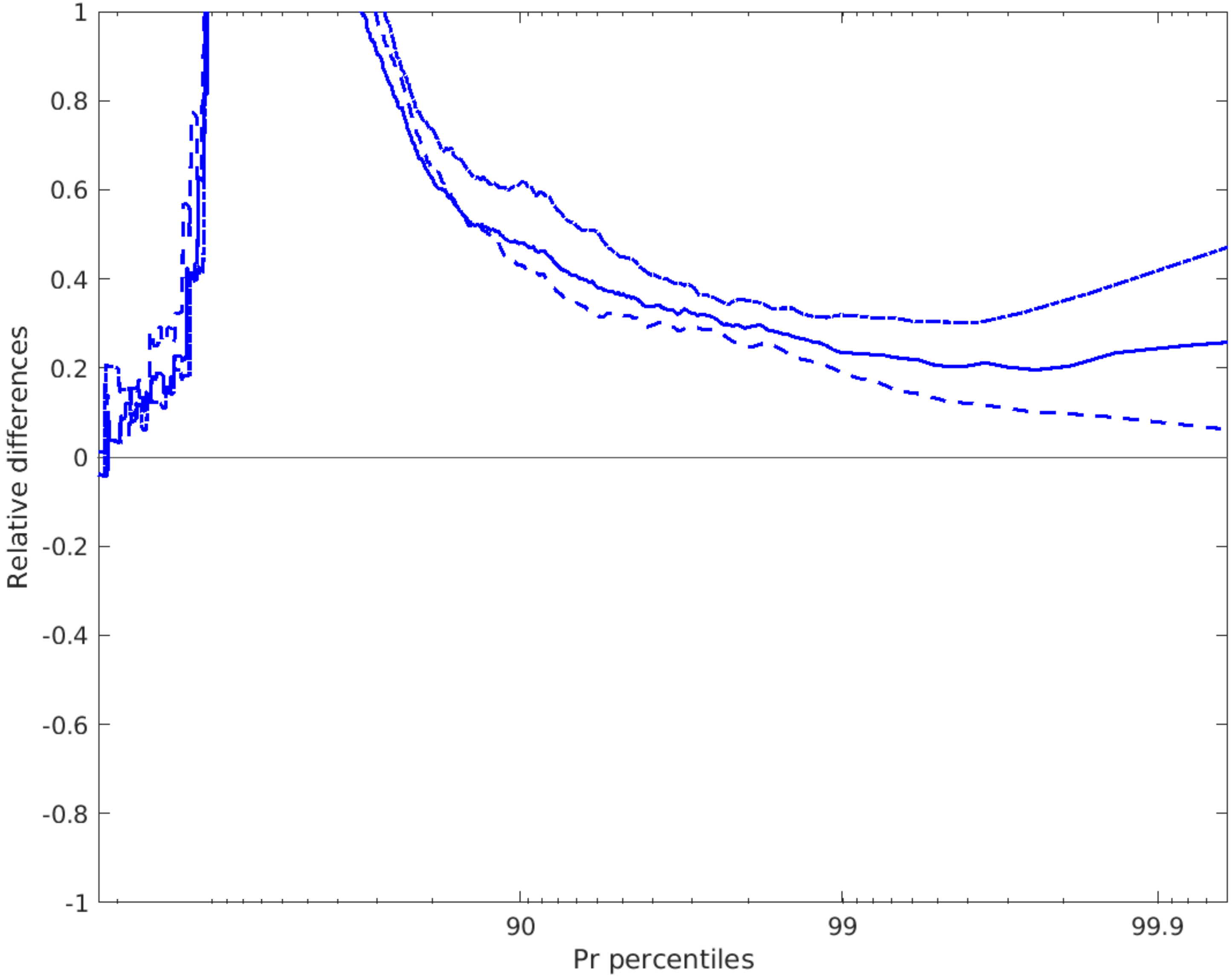
# Precipitation extremes with self-aggregation




⇒ increased instantaneous precipitation extremes (even more when time-accumulate)

*consistent with [Bao Sherwood 2019]*

# Precipitation extremes with self-aggregation




~ + 20% increase

⇒ + 20% increase of instantaneous precip extremes
(large variability with aggregation)

Why 20%?

# Theoretical scaling for precipitation extremes

*Precip efficiency* *Condensation*

$$\boxed{+20\%} \qquad \delta P \sim \delta\left[ \varepsilon_p \int \rho w \left(-\frac{\partial q_{sat}}{\partial z}\right) dz \right]$$

*Dynamic* *Thermodynamic*

[Muller Takayabu 2019]

# Theoretical scaling for precipitation extremes

*Precip efficiency*

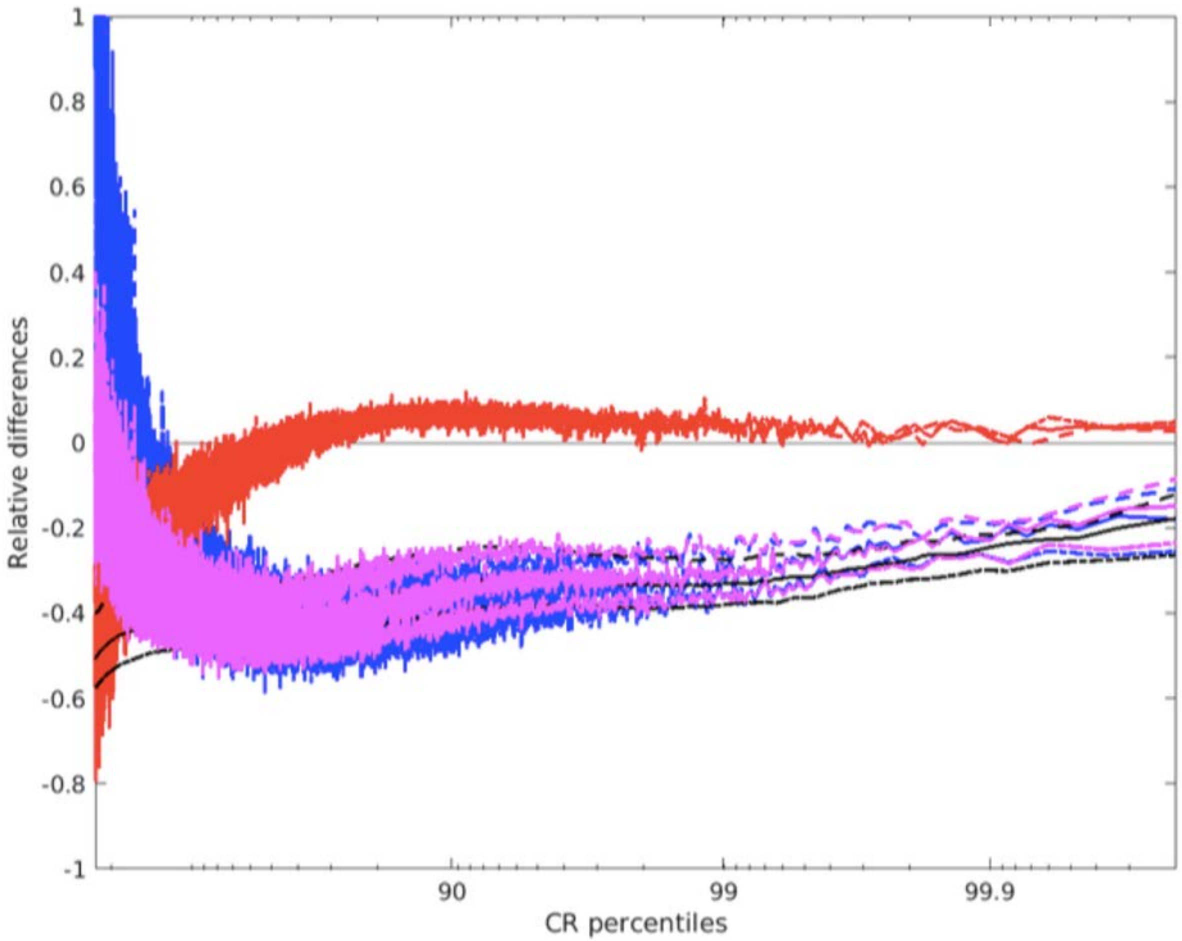
*Condensation* -15%

+20%

$$\delta P \sim \delta\left[\varepsilon_p \int \rho w \left(-\frac{\partial q_{sat}}{\partial z}\right) dz\right]$$

*Dynamic* -20%

*Thermodynamic* +5%




*Thermodynamic + 5%*

*Condensation rate -15%*

*Dynamic -20%*

# Theoretical scaling for precipitation extremes

Precip efficiency

Condensation

-15%

+20%

$$\delta P \sim \delta\left[\epsilon_p \int \rho w \left(-\frac{\partial q_{sat}}{\partial z}\right) dz\right]$$

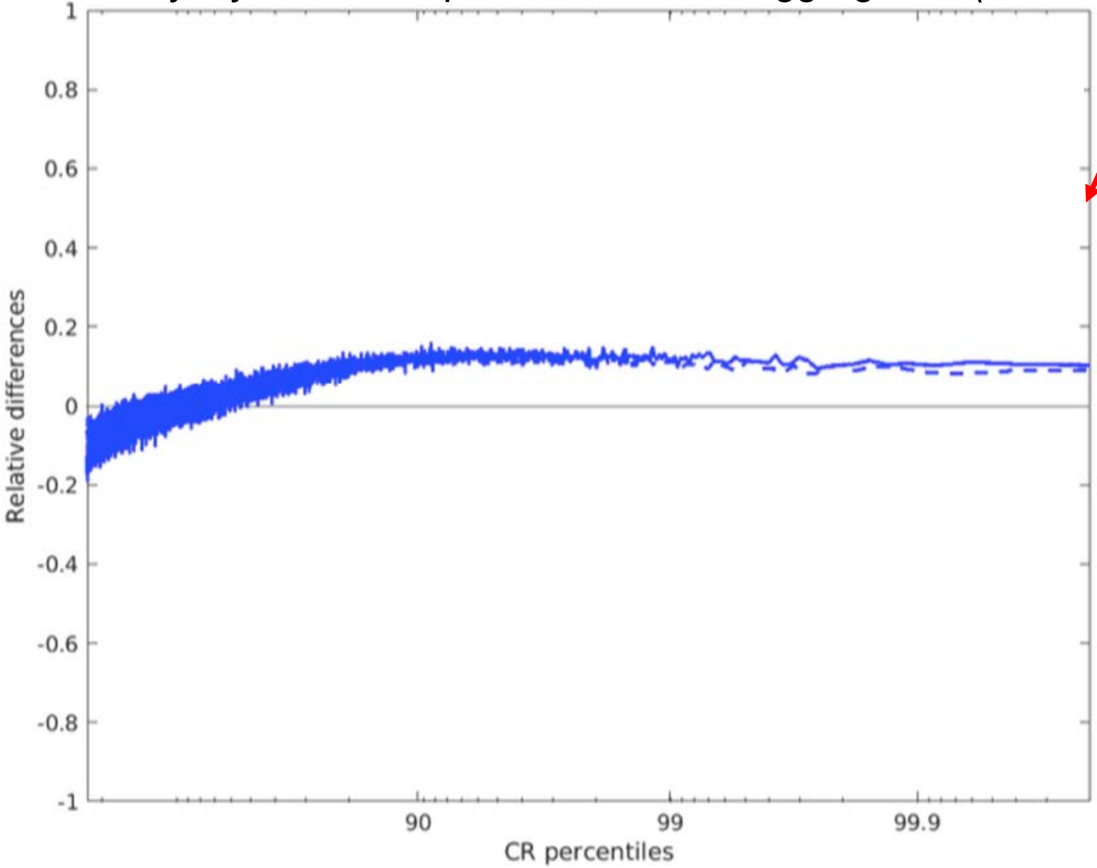
Dynamic

Thermodynamic

-20%

+5%

*Boundary layer water vapor increase with aggregation (~ +10%)*




Thermodynamic contribution linked to boundary layer water vapor

*[Muller 2013]*

Increase due to moister near-cloud boundary layer

Positive but small contribution

# Theoretical scaling for precipitation extremes

*Precip efficiency* — +20%

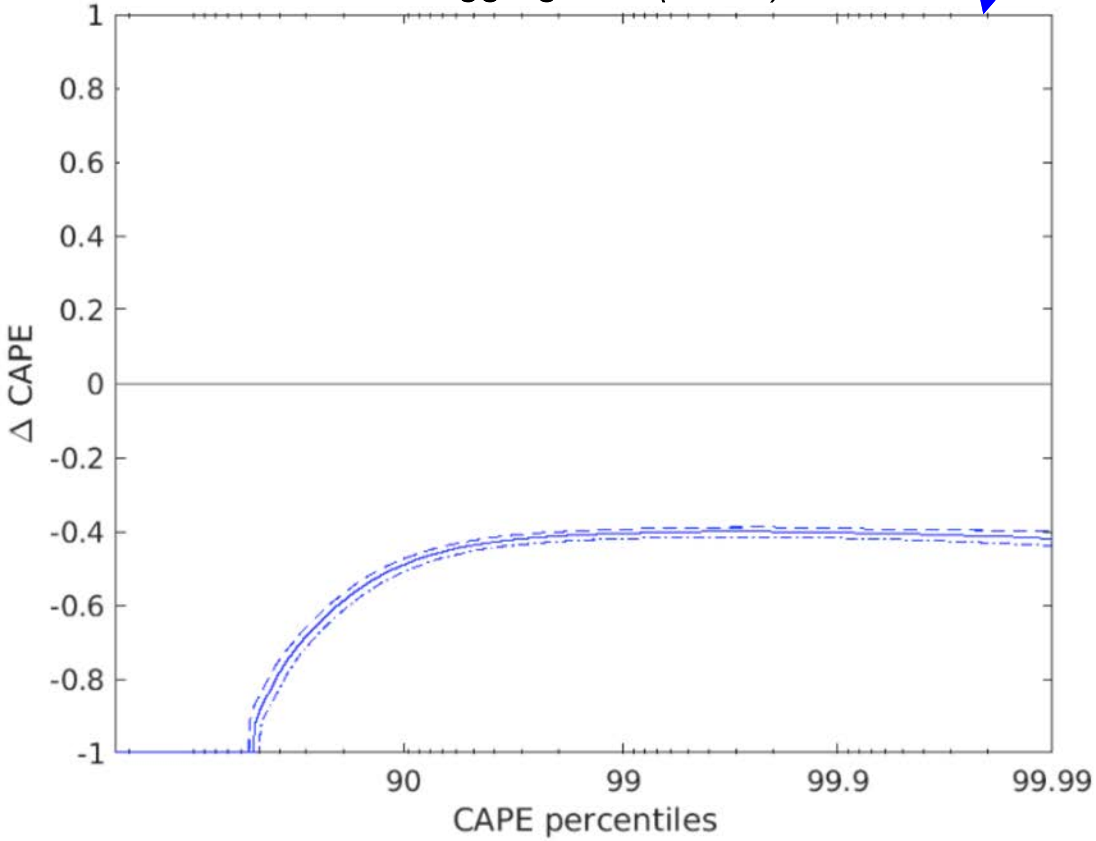
*Condensation* — -15%

$$\delta P \sim \delta \left[ \varepsilon_p \int \rho w \left( - \frac{\partial q_{sat}}{\partial z} \right) dz \right]$$

*Dynamic* — -20%

*Thermodynamic* — +5%

*Decrease in CAPE with aggregation (- 40%)*




Moister near-cloud conditions

⇒ less entrainment effect

⇒ Atmosphere closer to undilute temperature profile

Negative dynamic contribution consistent with decreased CAPE

# Theoretical scaling for precipitation extremes

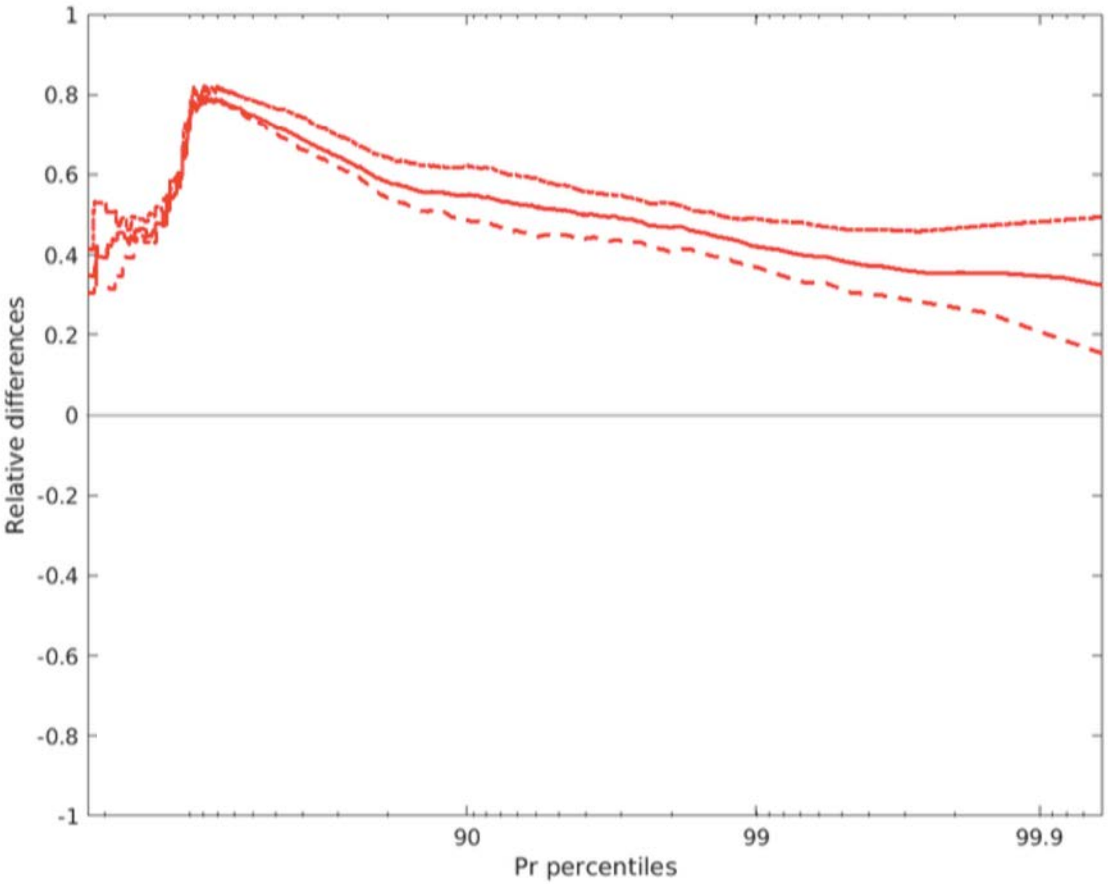
+35% *Precip efficiency* *Condensation* -15%

+20%

$$\delta P \sim \delta\left[ \epsilon_p \int \rho w \left( - \frac{\partial q_{sat}}{\partial z} \right) dz \right]$$

*Dynamic* *Thermodynamic*

-20% +5%




*Precip efficiency +35%*

# Theoretical scaling for precipitation extremes

+35% *Precip efficiency*

*Condensation* -15%

+20% $$\delta P \sim \delta\left[ \epsilon_p \int \rho w \left( - \frac{\partial q_{sat}}{\partial z} \right) dz \right]$$

*Dynamic* -20%

*Thermodynamic* +5%

## Efficiency $\varepsilon=\alpha(1-\beta)$ *[Lutsko Cronin 2018]*

Cloud condensate $q_n$ $\xrightarrow{\text{conversion } \alpha}$ precipitating condensate $q_p$ $\xrightarrow{\text{1 - rain evaporation } \beta}$ surface precipitation

+7% ($\int q_p / \int q_n$) +25% ($Pr_{sfc} / Pr_{max}$)

⇒ Reduced rain evaporation with aggregation dominates

- Due to moister conditions, and
- Faster terminal velocities from warmer temperatures (more rain less snow; no change in graupel)

# Conclusions

- Self-aggregation yields increased precipitation extremes

- Thermodynamic contribution positive but small
  Due to moister near-cloud boundary layer

- Dynamic contribution negative
  Due to decreased entrainment effects, thus decreased CAPE

- Precip efficiency contribution positive and largest
  Dominated by reduced evaporation of rain, from moister and warmer conditions (latter => faster terminal velocities)

  The contribution from organized convection to precip extremes is important (compare to 7%/K increase in « pop corn » convection »

*[Da Silva, Shamekh, Muller 2019 (in prep.)]*